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Hierarchical Design Method for Micro Device

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Abstract

Traditional mask-beginning design flow of micro device is unintuitive and fussy for designers. A hierarchical design method and involved key technologies for features mapping procedure are presented. With the feature-based design framework, the model of micro device is organized by various features in different designing stages, which can be converted into each other based on the mapping rules. The feature technology is the foundation of the three-level design flow that provides a more efficient design way. In system level, functional features provide the top level of schematic and functional description. After the functional mapping procedure, on the other hand, parametric design features construct the 3D model of micro device in device level, which is based on Hybird Model representation. By means of constraint features, the corresponding revision rules are applied to the rough model to optimize the original structure. As a result, the model reconstruction algorithm makes benefit for the model revision and constraint features mapping process. Moreover, the formulating description of manufacturing features derivation provides the automatic way for model conversion.

Keywords*: micro device, hierarchical design, feature mapping, model reconstruction*

1. Introduction

Along with the development of micro devices, traditional mask-begin design flow appears as obstacle to improving design efficiency. Especially for surface micromachining, more layers made mask design boring. In mechanical designing, features technology brings designers a more intuitive way. The designers are relieved from the fussy considering of fabricating issues at the design stage so as to pay more attention to the function and performance requirements. In micro device designing, it is just the beginning. MEMS feature modeling technique provides a reasonable way to construct the 3D model more efficiently [1,2], which is conformable with the top-down design methodology [3,4]. For mechanical parts, the features are often decomposed into a set of sub-features to satisfy the primitive machining operations [5]. However, for surface micromachining, the design features are liable to combine together to construct manufacturing feature that is organized with layer. The more reasonable approach can be characterized briefly as "function-to-shape-to-mask" [6]. To realize the shape-mask approach, the "inverse" design flow problems were studied as key issues [7]. Other works accomplished the mask creation by investigating the vertical topology [8] or genetic algorithm [9].

As mentioned above, efforts have been made to get the "function-to-shape-to-mask" design flow. However, because of the distinct feature orientation, there has been a hindrance to information flow between different design stages. So problem-solving in interlink between various features becomes a critical problem. The purpose of this thesis is to create an architecture that combines the feature technology with the three-level design framework. Furthermore, the key enabling technologies in feature conversion are presented. Currently, the method focuses on surface micromachining device.

2. The Feature-Based Design Framework

Based on feature technology, the three-level design flow of micro device is shown in Figure 1. As the foundation of the design flow, the key technologies involving the relation and transformation of distinct features are presented.

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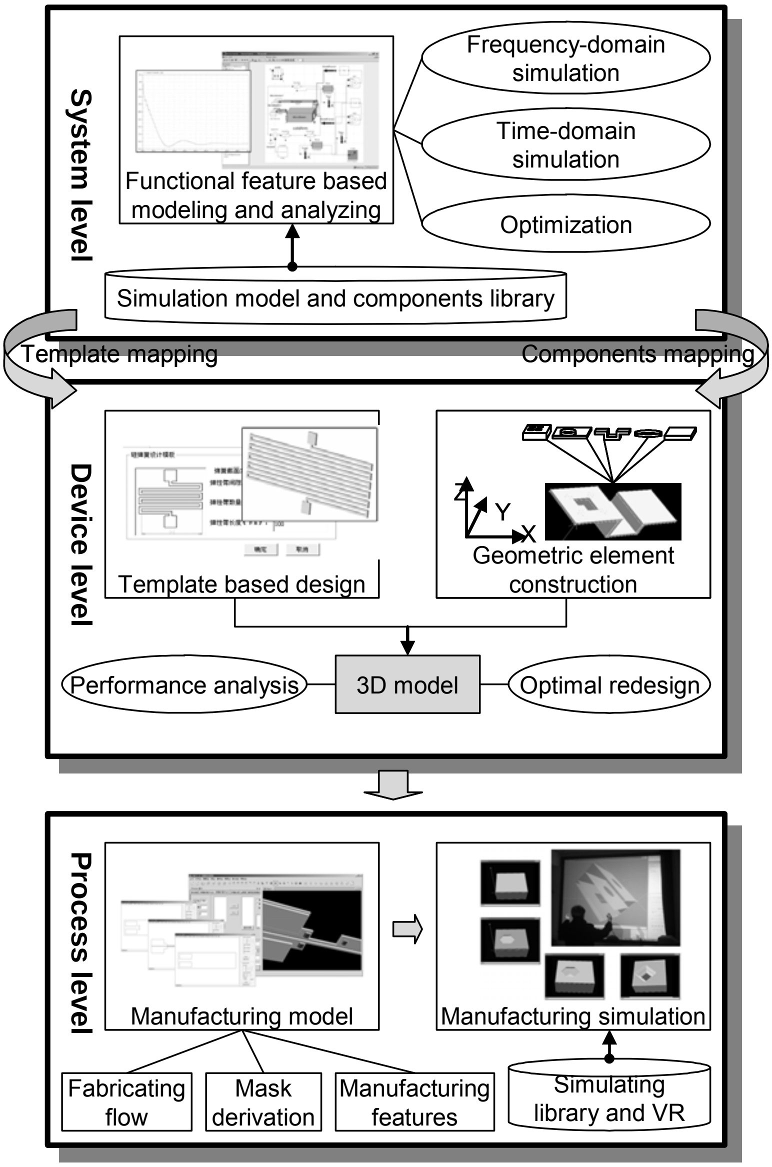

Figure 1. Three-level design flow

The feature technology is characteristic of this system is summarized as features-based modeling and feature-based optimization. Above all, the micro device model is constructed by feature technology. As shown in Figure 1, there are three ways to build the model. Functional features mapping is the normal way to construct model, which begins with the simulation components in functional features library. For the similar devices, based on the redesign theory, the template library is presented to support template-based design procedure. With parametric design template, for example, the micro spring can be redesigned with facility, which can be fabricated by LIGA process [10]. For those anomalous parts, direct geometric element constructing method is recommended. To optimize the rough model, the multi-physics simulating method is preferred, which is also a common way for the analyzing of traditional mechanical devices [11]. Besides the design rules checking, the process features and constraint features are essential for the model optimizing process. With these features, a three level modeling framework is constructed as shown in Figure 2. The system level modeling focuses on the function and behavior, while the process level modeling works at manufacturability. With features mapping procedure, these different features are connected to present an efficient design way throughout the whole design flow.

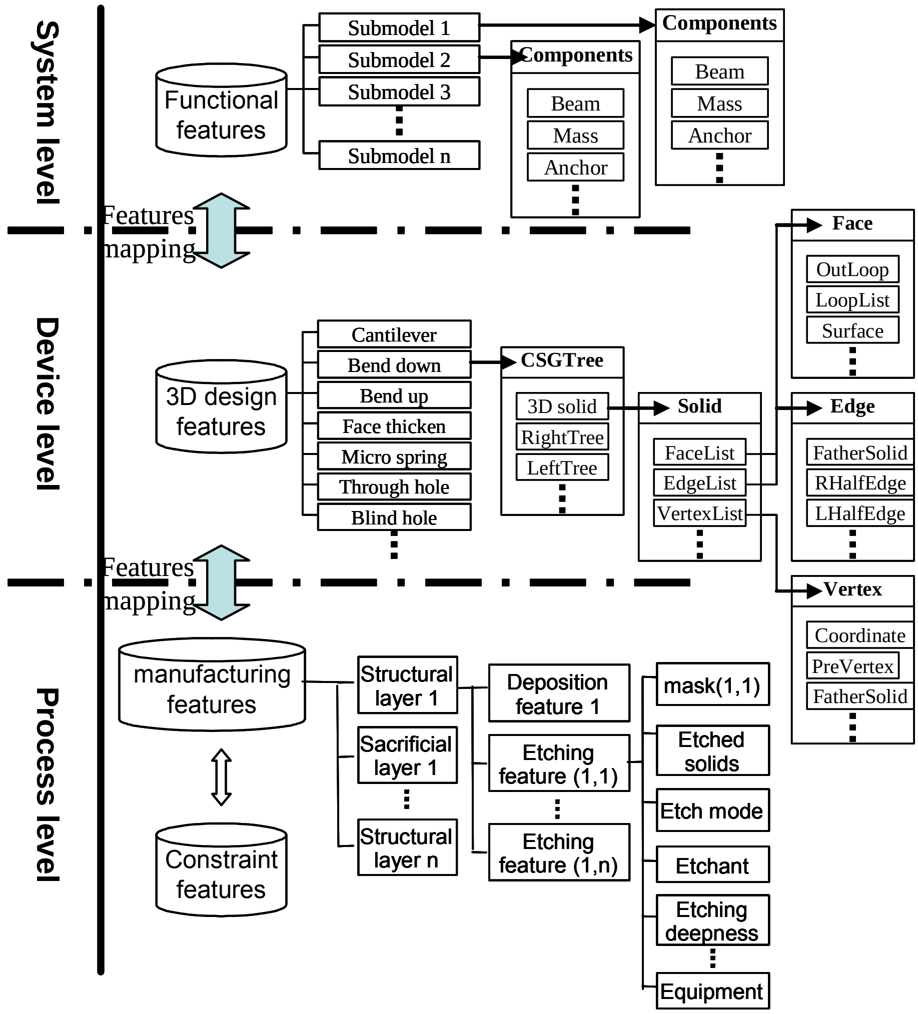

Figure 2. Features-based framework of three levels

1) Functional Features Mapping

In the system level, lumped bond graph is used to construct system dynamical simulation models to represent the functional requirements. The functional features library includes many physical simulation components. By the conversion from the predefined physical parameters to the geometric and material parameters, the functional features are mapping to the 3D design features. The mapping process is formalized by the macro script language to support the feedback between levels.

2) Manufacturing Features Mapping

The 3D design features are constructed in design module and function oriented normally, while the manufacturing features are fabricating oriented. They are organized with manufacturing layers. The mapping procedure is performed by means of algorithms including reference features generation and constraint applying procedure.

Above all, some design rules are applied to the geometric features to avoid conflicts in the following derivation steps. Taking the micro motor as the example, as shown in Figure 3, the 3D model is restricted with many rules.

3) Constraint for Features

Although performing the design rules checking, the features are still not good enough for manufacturing. The constraint features are used to restrict the geometric parameters for better manufacturability. Design features are associated with constraint features based on the mature processes. Here, MUMPs is adopted as the standard [12]. By the key issue, etched solids in sacrificial layers, the relationships between 3D design features and constraint features are constructed.

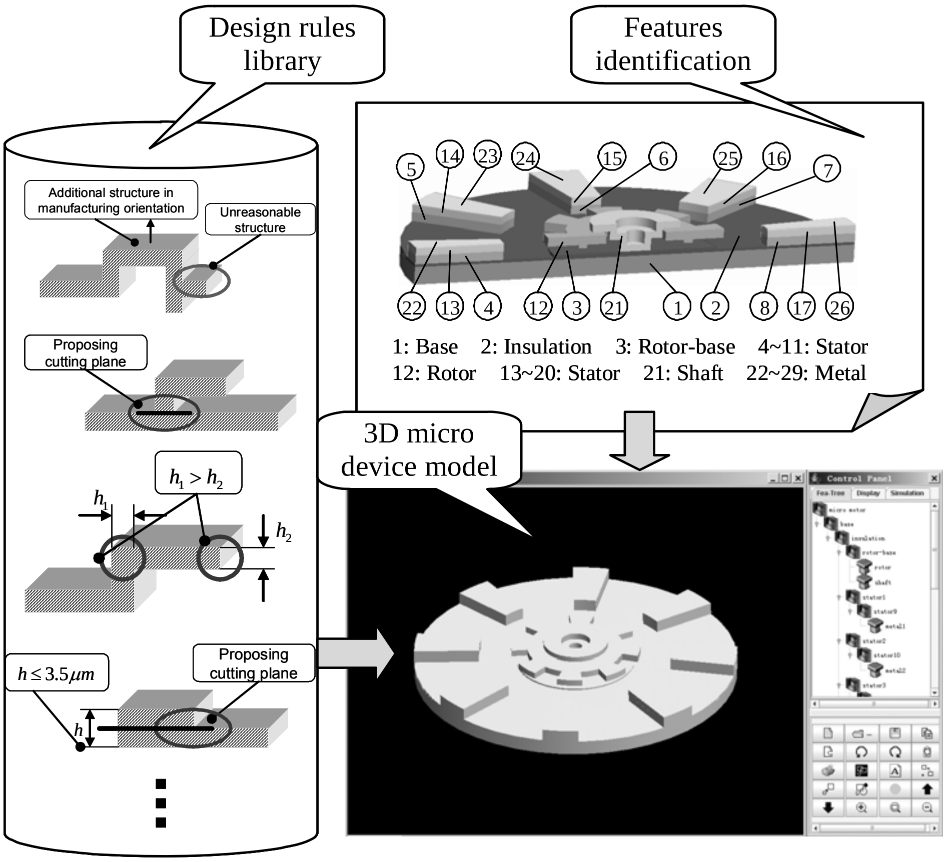

Figure 3. Applying constraint to 3d features

3. Mapping Device Features to Manufacturing Features

1) The Deposition feature of the ith Sacrificial Layer ($Dep(Sac)_i$)

The maximum height of the cantilever structure is got as the thickness of the deposition. It is represented as $h_{max}(Sac_i)$. $USML$ is the upper surface of layer. A protrusion operation is executed with the parameters of $h_{max}(Sac_i)$ and $USML$ of M_{i-1} to get $Dep(Sac)_i$. It is represented as UEO ($USML(M_{i-1})$, $h_{max}(Sac_i)$).

2) The Feature of Model Remained After the Etching of the ith Sacrificial Layer (Sac_i)

The deposition model of the sacrificial layer executes Boolean operation of Subtraction with the model of the ith structural layer to get Sac_i. It is represented as $BS(Dep(Sac)_i, L_i)$.

3) The Etched Solid Features of the ith Sacrificial Layer ($Ess(Sac_i)$)

The deposition feature of the sacrificial layer executes Boolean operation of Intersection with the feature of the ith structural layer to get $Ess(Sac_i)$. It is represented as $BI(Dep(Sac)_i, L_i)$ and illustrated in Figure 4.

4) The Deposition feature of the ith Structural Layer (Dep_i)

Firstly, the etching feature of the kth sacrificial layer (k<i) is revised if there is an intersection relation between L_i and Sac_k. Then, the thickness of the design features is calculated. The max value $h_{max}(L_i)$ is as the parameter of thickness for deposition. Finally, a protrusion operation is executed with the parameters of $h_{max}(L_i)$ and $USML$ of the combined solid of M_{i-1} and Sac_i to get $Dep(Sac)_i$. It is represented as $UEO(USML(BU(M_{i-1}, Sac_i)), h_{max}(L_i))$ and illustrated in Figure 5.

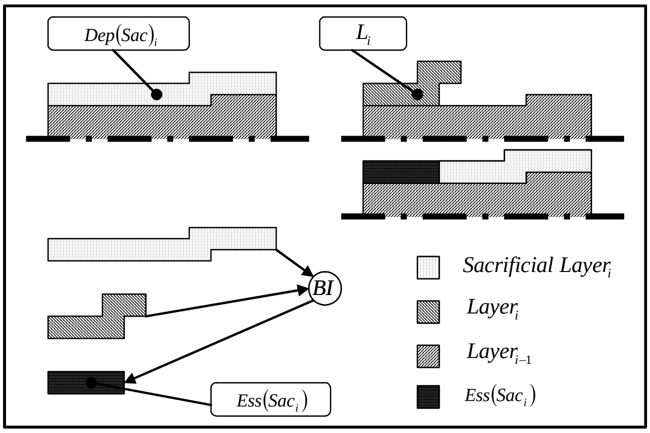

Figure 4. Etched solid features of sacrificial layer

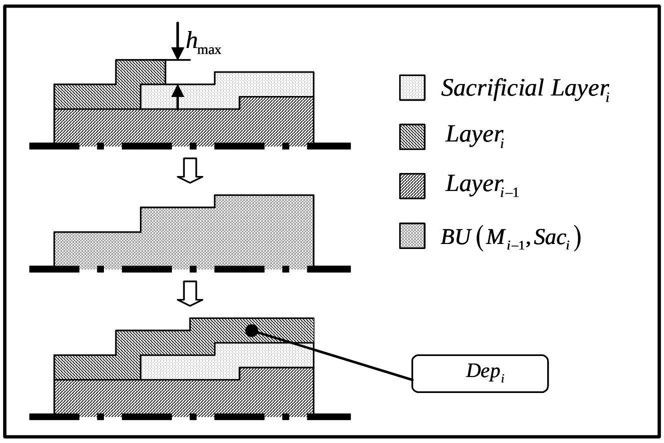

Figure 5. Deposition feature of structural layer

5) The Etched Solid Features of the ith Structural Layer ($Ess(L_i)$)

The deposition model of the structural layer executes Boolean operation of Subtraction with L_i to get $Ess(L_i)$. It is represented as $BS(Dep_i, L_i)$ and illustrated in Figure 6. $Ess(L_i)$ is the set of the etched solid features.

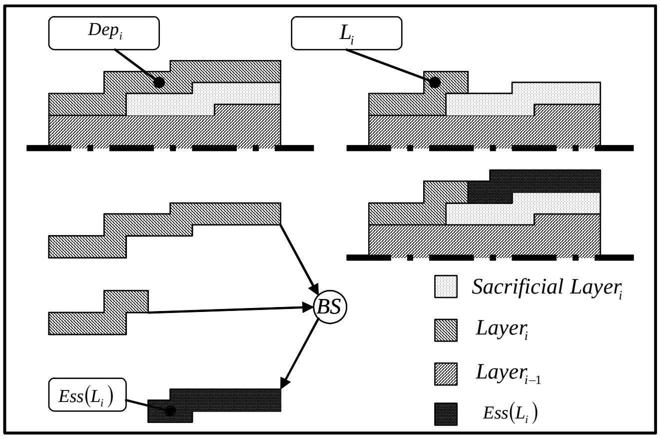

Figure 6. Etched solid features of structural layer

The results of the above mapping procedure are reference manufacturing features, which are the foundation of the following reconstructing process. Although the primary features are constructed, the manufacturability is not good enough. Therefore, the constraint and revision are necessary.

4. The Constraint for Manufacturing Features and Reconstructing Procedure of Feature Model

4.1. Applying the Constraint to Structural Layer Features

The steps of applying the constraint to the structural layer features are illustrated in Figure 7. Firstly, the reference features of the ith sacrificial layer are calculated to pick up $Ess(Sac_i)$. Then, the reference mask set of the i-1th and ith structural layers is calculated, which is reference for the following comparing step. Finally, the projection pattern of the etched solid is compared with the reference mask. The reference mask is revised based on the manufacturing constraint rules. Based on the revised mask, the structural features are reconstructed.

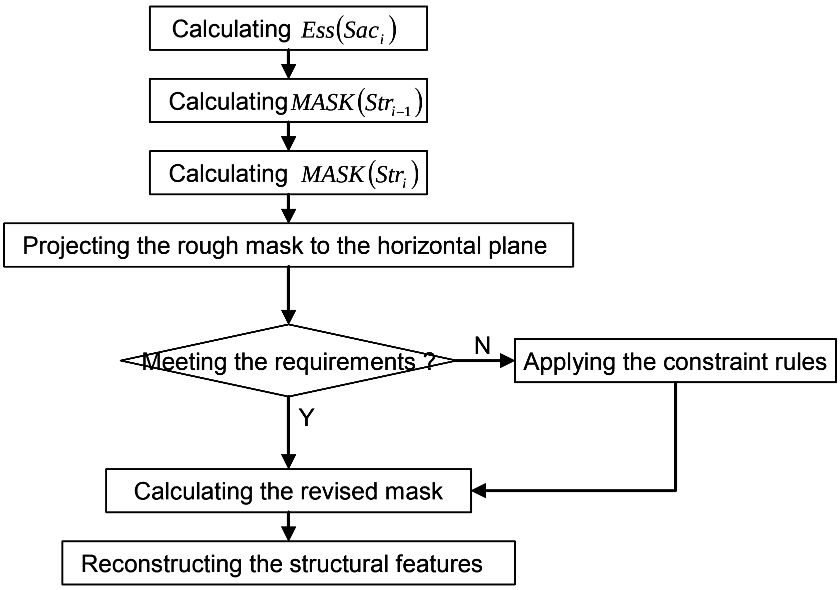

Figure 7. Applying the constraint to structural layer features

To explain this procedure, the derivative process about Es_1 in $Ess(Sac_4)$ of the micro motor is illustrated as an example. It is shown in Figure 8. Associated with the constraint feature, Es_1 is an instance of constraint feature ANCHOR1. Some rules about ANCHOR1 are as follows.

Rule A: POLY0 space to ANCHOR1 by 4.0μm. The necessary separation between POLY0 and ANCHOR1 hole is to ensure that POLY0 is not exposed.

Rule B: POLY0 enclose ANCHOR1 by 4.0μm. The distance necessary between the edge of POLY0 and an ANCHOR1 hole to ensure the hole does not extend beyond the edge of POLY0.

Rule C: POLY1 enclose ANCHOR1 by 4.0μm. The amount that POLY1 must extend beyond the edge of an ANCHOR1 hole to ensure complete coverage of the hole.

The feature of Es_1 is restricted with these rules. It is only illustrate the mask-revision process with the rule C. Firstly, the reference mask of POLY1 is extracted. Secondly, the boundary of Es_1 is projected to horizontal plane and compared with the reference mask. Without revising, normally, the boundaries coincide. It is obviously poor manufacturability for the reference mask set. Finally, with the rule C, the boundary of the mask extends beyond that of Es_1 to a distance of δ (δ≥4.0μm). For the other etched solids, it is the similar process.

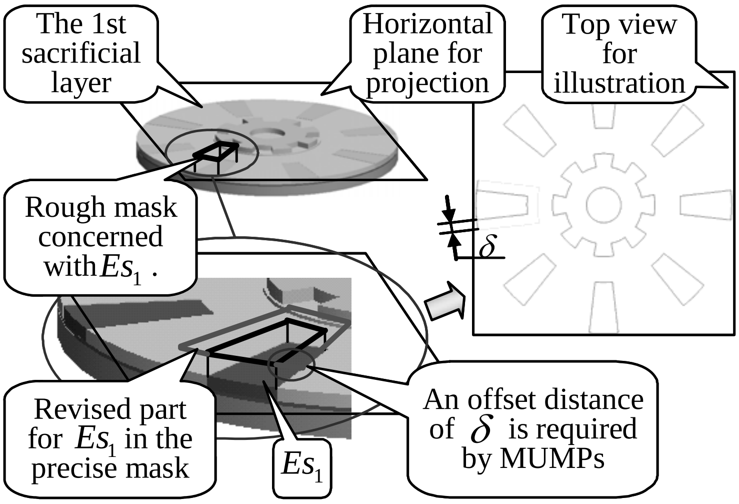

Figure 8. Constraining the manufacturing features of micro motor

4.2. Reconstructing Features of Structural Layer

The features of L_{i-1} and L_i are reconstructed with the revised mask and corresponding reference features. Above all, the reference deposition features are obtained, which is the foundation of the etching operation. The necessary loop information is got by the inversed pattern of precise mask of the structural layer. Then, the etched part is constructed by executing the extrude operation with the loop data and the deepness of etching feature. With the deposition and etching parameters, the revised features of the structural layer are calculated by the Boolean operation of subtraction between the deposition model and the etched part. The reconstruction process for features of L_4 of the micro motor is illustrated in Figure 9. In addition, these procedures of reconstruction make influence on the model of sacrificial layer. A reconstruction of the affected model is necessary. Fortunately, sacrificial layer is removed before the micro device works. It makes no influence on the final performance. Therefore, it is fixed on the premise that the structural model meets the functional requirements. The reconstruction of corresponding sacrificial layer model is made after functional analysis.

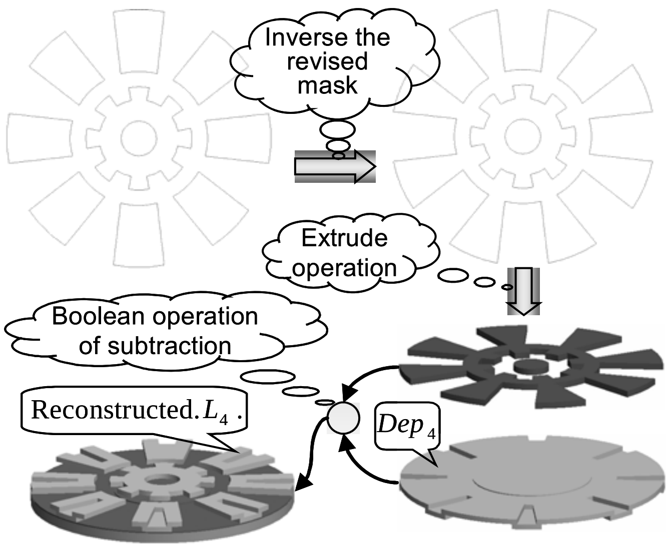

Figure 9. Feature reconstruction of structural layer

4.3. Reconstructing Features of Sacrificial Layer

The features of sacrificial layer are reconstructed based on the model of the structural layers close above and below it. As an instance, the reconstructive process of the features concerning Sac_4 of the micro motor is illustrated in Figure 10. The revised features about L_3 and L_4 of the micro motor are derived in the preceding step. Firstly, $USML(M_3)$ is picked up. The thickness for extrude operation is got by the cantilever structural information of the revised L_4. With $USML(M_3)$ and the thickness, the deposition feature of the sacrificial layer is calculated by the extrude operation. Secondly, the etching feature is derived by executing Boolean operation of subtraction between the revised $Dep(Sac)_4$ and L_4. Finally, these reconstructed manufacturing features make up of the manufacturing model for the sacrificial layer.

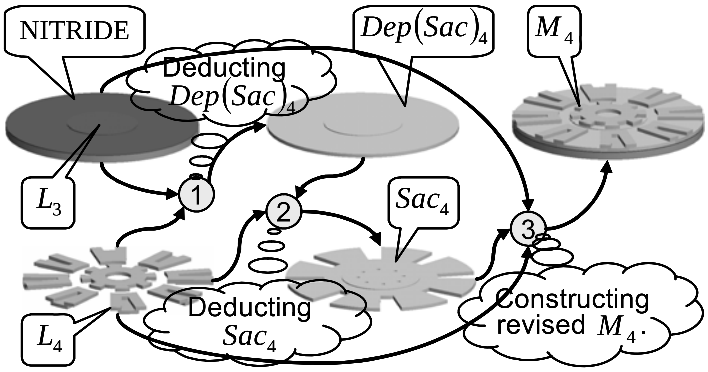

Figure 10. Feature reconstruction of sacrificial layer

With the above-mentioned constraint applying and features reconstructing processes, the revision of manufacturing features around the ith sacrificial layer is finished. Similar processes are carried out around the other sacrificial layers. Because of the affection of the later steps, it is likely to revise the model fixed in the former steps. Therefore, in view of the overall situation, this revision is a spiral process from the lower layers to the upper together with some necessary returns.

5. Conclusion

This paper presents a feature-based design framework of micro device. The main contribution lies in the three-level hierarchical system of features, by which the "function-to-shape-to-mask" design flow is achieved. The mapping procedure between different levels constructs the linkage of various features. In addition, the constraint of manufacturing features improves the manufacturability. As a starting point, this paper focuses on the micro device fabricated by surface micromachining process. Future work will be emphasized on bulk micromachining process.

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